



Plant-Bacterial Interactions: A Latent Alliance for Growth Promotion and Environmental Stress Tolerance /A Review Article

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Abstract: This encapsulates the general relationship between plant and bacteria in the natural and agricultural ecosystem. It is based on the activities of useful bacteria, such as plant growth-promoting bacteria (PGPRs) and nitrogen-fixing bacteria, in promoting plant growth and plant tolerance to stressful situations regarding pollution, salinity, and drought. The article also mentions that the bacteria maintain plant health by secretion of phytohormones, nitrogen fixation, solubilization of phosphate, and production of antibiotics against pathogenic bacteria. The article also mentions the existing applications of the interaction in sustainable agriculture and bioremediation of contaminated soils.

Keywords: Environmental Pollution, Bioremediation, Metals, Augmenting Environmental Quality



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1-Introduction: Plant-bacteria associations are an important interaction in ecosystems, playing crucial roles in plant growth promotion, nutrient acquisition, and plant tolerance to abiotic and biotic stresses. Most evident among these interactions is the symbiotic relationship of plants with nitrogen-fixing rhizobia that infect legume root nodules. These bacteria are involved in nitrogen fixation of atmospheric nitrogen that cannot be used by plants into the usable forms by plants such as nitrate and ammonia for optimizing increased productivity by plants (Oldroyd *et al.*, 2011). Besides, there are such PGPRs as *Pseudomonas* and *Bacillus*, which enhance the growth of plants by affecting a number of mechanisms. They include the synthesis of plant hormones such as auxins, gibberellins, and cytokinins, phosphorus solubilization, nitrogen fixation, and plant resistance to disease (Lugtenberg & Kamilova, 2009). The bacteria also have antifungal metabolites and degradation of pathogenic enzymes, which trigger plant health and yield (Glick, 2012).

In polluted soil, some bacteria such as *Azospirillum* and *Burkholderia* were reported to enhance plant resistance to heavy metal pollutants through different mechanisms involving the excretion of organic acids and chelating agents, which detoxify metals and promote plant growth (Ma *et al.*, 2011).

In the recent past, studies have shown that *Rhizobium* and *Sinorhizobium* bacteria also enhance the ability of the plants to detoxify pollutants by enhancing their uptake capacity and arresting their toxicity effects (Sessitsch *et al.*, 2013). Their performance is determined by a range of parameters such as plant species, species of bacteria, soil, and intensity of environmental stress. The greater use of beneficial bacteria in sustainable agriculture and ecosystem management has been shown to have an immense potential as a response to climate change and food security (Vessey, 2003).

Plant-Associated Bacteria

The vast majority of bacteria are directly or indirectly related to plants. Depending upon the mode of their interaction, they are classified as commensally bacteria, growth-promoting beneficial bacteria, or pathogenic bacteria. The most crucial among these classes are:

1. Nitrogen-fixing Bacteria: This category consists of bacteria that can fix atmospheric nitrogen not available to plants in a usable form like ammonia and nitrate. This is crucial for plant development in nitrogen-deficient soils. The most common of these kinds are:

***Rhizobium*:** These bacteria live in association with legumes and develop root nodules that serve as nitrogen-fixing centers (Oldroyd *et al.*, 2011).

***Azospirillum*:** These bacteria colonize the rhizosphere and have the ability to partially fix nitrogen and secrete growth-promoting hormones (Bashan & de-Bashan, 2010).



Frankia: It occurs in symbiosis with some non-legume tree plants, such as alder, and fixes nitrogen (Wall, 2000).

2. Plant Growth-Promoting Rhizobacteria (PGPR): These bacteria promote plant growth through different mechanisms such as plant hormone production, phosphate solubilization, nitrogen fixation, and increased disease resistance. Most well known among these are:

Pseudomonas: Characterized by the production of antibiotics and fungal wall-degrading enzymes, thus rendering the plants more resistant to disease (Lugtenberg & Kamilova, 2009).

Bacillus: Characterized by the production of antimicrobial compounds and plant growth-promoting compounds, it is largely implicated in disease control (Glick, 2012).

Enterobacter: Helps in nitrogen fixation and phosphate solubilization, and also renders the plants more tolerant to salinity and drought (Egamberdieva *et al.*, 2017).

3. Endophytic Bacteria: Bacteria capable of colonizing plant tissues (roots, leaves, stems) without causing disease symptoms. They may even induce plant immunity and make it capable of withstanding biotic and abiotic stresses. Examples include: *Burkholderia*, *Herbaspirillum*, *Acetobacter* (Sessitsch *et al.*, 2013).

These organisms have the ability to produce growth-stimulating substances and alleviate salinity and heavy metal contaminant-induced stress.

4. Phytopathogenic Bacteria: This group is responsible for many plant diseases such as wilt, rot, and blight. Most common are:

Xanthomonas: Causes blight and wilt in many crops.

Pectobacterium (formerly *Erwinia*): Causes soft tissue rot.

Agrobacterium tumefaciens: Causes crown galls on plants (Agrios, 2005).

The presence of these species can reduce agricultural production and require the application of biological or chemical treatments.

Plant Root Bacteria (Rhizobacteria)



Plant root bacteria, or rhizobacteria, constitute an important part of the microbial community in the rhizosphere, the minute area surrounding the roots where plants interact with microorganisms. They are characterized by their ability to exist in the surrounding area of or on the root surface without causing pathogenicity, but rather contributing significantly towards plant growth promotion and health. Rhizobacteria are often classified into two general categories:

1. Plant Growth-Promoting Rhizobacteria (PGPR): This is the most studied group of rhizobacteria since they are able to promote plant growth and productivity through various mechanisms:

Nitrogen Fixation: Some of the rhizobacteria,, *Azospirillum* and *Rhizobium*, are able to fix atmospheric nitrogen and convert it to a form that is usable by plants (Vessey, 2003).

Plant hormone production: They synthesize growth regulators such as auxins (IAA), cytokinins, and gibberellins that are involved in root growth promotion and branching (Glick, 2012).

Phosphate solubilization: Some rhizobacteria secrete enzymes or organic acids which solubilize phosphates in the soil, making it available for the plant (Rodríguez & Fraga, 1999).

Improving plant disease resistance: Some species, e.g., *Pseudomonas fluorescens* and *Bacillus subtilis*, are able to produce antibiotics and enzymes that kill the walls of fungi that cause disease, in addition to triggering induced systemic resistance (ISR) in plants (Lugtenberg & Kamilova, 2009).

2. Pathogenic Rhizobacteria: Some species of rhizobacteria are pathogenic and are able to cause symptoms such as wilting, root rot, or stunted plant growth. These include:

Agrobacterium tumefaciens: causes crown lesions on a broad host range of plants (Agrios, 2005).

Ralstonia solanacearum: a very pathogenic bacterium that causes bacterial wilt on a large number of economic crops (Hayward, 1991).

Rhizobacteria play an important role in improving soil quality, plant growth induction, and plant tolerance to environmental stresses such as salinity, drought, and heavy metal contamination. Rhizobacteria are now an essential part of sustainable agriculture and bioremediation approaches for the restoration of contaminated soils (Backer *et al.*, 2018).



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Endophytic Bacteria: *Endophytic bacteria* are important soil and plant-carried microbes. They live within the tissue of plants (roots, stem, leaves, flowers, and seeds) without displaying obvious symptoms of disease (Hardoim *et al.*, 2015). Endophytic bacteria have a major contribution to the soil microbial community of plant-related organisms with an important role in improving the well-being of the plant and in facilitating plants to deal with fluctuating environmental conditions.

These bacteria invade internal plant tissues through various channels, during nutrient and water absorption through root hairs. Through wounds or natural openings such as stomata and lenticels (Santoyo *et al.*, 2016). After invading, they take up residence in plant tissues and exert positive functions without damaging the host in any detectable manner.

Some of the most important genera that exemplify endophytic bacteria include: *Bacillus*, *Pseudomonas*, *Enterobacter*, *Burkholderia*, *Serratia*

These genera also differ in their ability to synthesize growth-promoting bioactive metabolites and enzymes that increase plant stress tolerance.

Role of Endophytic Bacteria in Plant Stimulation

Plant growth stimulation: They produce growth regulators such as auxins, cytokinins, and gibberellins, which stimulate root development and plant growth (Ryan *et al.*, 2008).

Increasing nutrient uptake: Through biological nitrogen fixation and solubilization of phosphates and insoluble minerals (Lodewyckx *et al.*, 2002).

Increasing resistance to stress: Enhances plant salinity, drought, heavy metal, and biotic stresses such as tolerance to diseases (Compant *et al.*, 2010).

Protection from diseases: Through the production of antibiotics and pathogen-suppressing enzymes.

The Role of Endophytic Bacteria in Sustainable Agriculture

Endophytic bacteria play a crucial role in sustainable agriculture and environmental biotechnology as they provide nature-friendly substitutes for chemical fertilizers and pesticides. They are also used in bioremediation processes for removing soil and water pollution (Khan *et al.*, 2020).

Plant Growth-Promoting Bacteria



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Plant growth-promoting bacteria (PGPB) are among the most promising microbes that have their services to offer for enhanced higher plant productivity and tolerance of environmental stresses through a range of direct and indirect biological processes (Glick, 2012). The microbes are composed of a range of different genera such as *Pseudomonas*, *Bacillus*, *Azospirillum*, *Rhizobium*, and *Enterobacter*, occur in a range of diverse environments such as soil, roots, and even inside plant tissues (Lugtenberg & Kamilova, 2009).

First: Direct Mechanisms: Synthesis of Plant Growth Regulators (Phytohormones): They produce plant hormones such as auxins (IAA), cytokinins, and gibberellins that stimulate root growth, cell division, and increase the surface area for water and nutrient uptake (Patten & Glick, 2002).

Atmospheric Nitrogen Fixation: Some of the bacteria, for example, *Rhizobium* and *Azospirillum*, can fix nitrogen and provide it to the plant in a form that can be utilized by the plant and hence reduce the use of nitrogen fertilizers (Bhattacharyya & Jha, 2012).

Phosphate Solubilization: Other species solubilize unavailable phosphate in the soil via organic acid and enzyme production for phosphorus accessibility by plants for growth (Rodríguez *et al.*, 2006).

Production of Siderophores: These produce compounds that chelate iron and convert it into forms that are available to plants, providing satisfactory plant nutrition (Ahmed & Holmström, 2014).

Second: Indirect Mechanisms:

Pathogen control: Certain species produce antibiotics and cytolytic enzymes, including chitinase and glucanase, which inhibit the growth of pathogens (Compant *et al.*, 2005).

Induction of systemic resistance (ISR): They induce the plant defense mechanism to be hardened against biological attacks by initiating defense cascades including ammoniac acid and salicylic acid pathways (Pieterse *et al.*, 2014).

Environmental stress tolerance: They induce drought stress tolerance, salt stress tolerance, and heavy metal stress tolerance in plants through regulation of endogenous plant hormones and by production of antioxidants (Vurukonda *et al.*, 2016).

Relevance of the mechanisms



These mechanisms are the basis of sustainable agriculture practice, minimizing the use of chemical pesticides and fertilizers and improving crop quality and yield even in the case of degraded and contaminated conditions.

The Role of Bacteria in Plant Tolerance to Environmental Stresses

Plant growth-promoting bacteria (PGPB) and plant-associated bacteria play an important role in bestowing plants with environmental stress tolerance such as drought, salinity, heat, and heavy metals (Vurukonda *et al.*, 2016). Plant-associated bacteria and growth-promoting bacteria possess physiological and biochemical properties that allow them to facilitate plants in tolerating adverse environmental conditions and thus contribute to their development and productivity.

A : Tolerance to Drought: Some of the endophytic bacteria and rhizobacteria also produce osmolytes such as proline and polysaccharides, which regulate the osmotic pressure of plant cells during drought stress (Ngumbi & Kloepper, 2016). The bacteria also stimulate increased production of abscisic acid (ABA), which regulates stomatal closure and reduces water loss (Yang *et al.*, 2009).

B: Soil Salinity Tolerance: Under saline conditions, microorganisms synthesize enzymes and plant hormones controlling distorted root growth, facilitating water uptake, and reducing toxic sodium ions (Na⁺) ions buildup. *Bacillus* and *Pseudomonas*, for example, trigger plant salinity tolerance (Egamberdieva *et al.*, 2017).

C: Heat Stress Tolerance: Other research has found that growth-promoting bacteria trigger the production of heat shock proteins, which provide protection against heat injury to plant cells and consequently the maintenance of enzymic activity in the plant (Rolli *et al.*, 2015).

D: Prevention of the Effect of Heavy Metals: Some microorganisms are capable of detoxifying heavy metals such as lead (Pb), cadmium (Cd), and mercury (Hg) effectively through mechanisms that include metal fixation, siderophore chelation, and removal of chelating compounds (Chela-Traja) (Ma *et al.*, 2016). The mechanisms inhibit the accumulation of harmful metal by the plant or convert it into less harmful forms, hence promoting its potential growth in the contaminated soil.

E: Activation of Natural Defenses: These bacteria make the plant form antioxidants like superoxide dismutase and catalase, which inhibit the accumulation of toxic free radicals from other environmental stresses (Backer *et al.*, 2018).



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Applications of Plant-Bacteria Associations in Sustainable Production and Pollution Control. A deep understanding of the symbiotic relationship between plants and bacteria has developed new sustainable agriculture technologies and preparing the shock of environmental pollution (Backer *et al.*, 2018). Plant-associated bacteria, particularly plant growth-promoting bacteria (PGPB), are effective bio-agents that can be utilized for enhancing crop production and restricting the use of chemical pesticides and fertilizers (Bhattacharyya & Jha, 2012).

They are subsequently used in sustainable agriculture to generate "biofertilizers" that enhance soils with the capability of nitrogen fixation from the air (*Rhizobium*, *Azospirillum*). These bacteria provide a green alternative source of nitrogen to chemical fertilizers, which help prevent groundwater pollution and climate-unfavorable nitrous oxide emissions (Rana *et al.*, 2020). Other organisms such as *Bacillus* and *Pseudomonas* also produce plant growth regulators such as auxins and cytokinins that enhance the growth of the root system and optimize the efficiency of water and nutrient absorption (Vessey, 2003).

Bacteria play a vital role in the bioremediation of water and soil pollution in the degradation or de-toxication of toxic chemicals such as heavy metals (lead, cadmium, mercury), pesticides, and petroleum hydrocarbon wastes from water and soil (Ma *et al.*, 2016). Some endophytic and rhizobacterial species secrete siderophores, organic acids, and chelating agents that chelate pollutants and reduce them to a less toxic or plant-nonavailable form, which allows plants to thrive in contaminated environments (Rajkumar *et al.*, 2012). Bacteria may also improve the efficiency of plants in phytoremediation activities through enhanced ability to uptake, fix, or decompose pollutants (Glick, 2010).

Resisting Climate Stress and Climate Change

These microbes help to counter environmental stresses due to climate change such as drought, salinity, and temperature. This ensures stability in plant production under fluctuating environments and helps to achieve food security with environmental protection (Ngumbi & Kloepper, 2016).

The judicious and thoughtful application of such biological interactions enhances the success of achievement of sustainable agricultural goals, improves the efficiency of the use of natural resources, and reduces reliance on chemical alternatives that would further exacerbate the environment.

Conclusion:



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- 1- Importance of the plant-bacteria association: Bacteria play a crucial role in enhancing the growth of plants and their resistance to harsh environmental factors such as pollution, salinity, and drought.
- 2- Plant growth-promoting bacteria (PGPR): *Pseudomonas* and *Bacillus* bacteria are some of the PGPR that enhance the growth of plants through the production of plant growth regulators such as auxins, gibberellins, and cytokinins, solubilization of phosphate, and nitrogen fixation.
- 3- The role of bacteria in heavy metal pollutant resistance: *Azospirillum* and *Burkholderia* bacteria are involved in encouraging plant resistance against heavy metal pollutants by releasing organic acids and metal-chelating compounds that demodulate metal.
- 4- Improve the uptake ability of plants for pollutants: *Rhizobium* and *Sinorhizobium* bacteria improve the plant's ability to absorb pollutants and minimize their toxic effect.
- 5- Rhizobacteria: Rhizobacteria play a major role in improving soil health and plant resistance to environmental stresses such as salinity stress and heavy metal pollution.
- 6- Plant Pathogenic Bacteria: Plant pathogenic bacteria, such as *Xanthomonas* and *Agrobacterium tumefaciens*, cause disease in plants, leading to reduced agricultural productivity and the need for biological or chemical control.
- 7- Endophyte Bacteria and Their Utilization in Sustainable Agriculture: *Endophyte bacteria such as Bacillus and Pseudomonas* are known to induce plant growth, increase nutrient uptake, and increase their resistance to environmental stresses.
- 8- Environmental and Agricultural Uses: Beneficial bacteria are used in sustainable agriculture for the manufacture of biofertilizers, raising crop yields, and minimizing chemical fertilizer and pesticide usage, and bioremediation of pollutants in water and soil.
- 9- Environmental Stress Reduction: Bacteria play a role in the enhancement of plant resistance to various environmental stresses by synthesizing antioxidants and maintaining the concentration of plant hormones.
- 10- Bacteria are an essential component of natural and agricultural ecosystems, involved in plant growth, improvement of environmental stress tolerance in plants, and



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enhancement of soil fertility, hence forming a useful asset in sustainable agriculture and environmental pollution management.

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